Analytical and numerical methods for processing hopkinson bar loaded bending test on concrete : a comparative study

B. Durand, Franck Delvare, Jean-Luc Hanus, Patrice Bailly

Analytical and numerical methods for processing Hopkinson Bar Loaded Bending test on concrete: a comparative study

B. Durand[1,2], F. Delvare[1], J.L. Hanus[1], P. Bailly[1]

[1] *Institut PRISME, ENSI de Bourges, France, {bastien.durand,franck.delvare,jean-luc.hanus, patrice.bailly}@ensi-bourges.fr*
[2] *Institut National de l'Environnement Industriel et du RISque, Verneuil-en-Halatte, France*

Risk assessment tools for concrete structures subjected to dynamic loading such as explosions or impacts require information on dynamic characteristics of concrete. Various techniques have been used to test concretes at high strain rates. Among these different techniques, various tensile tests based on Split Hopkinson Pressure Bars (SHPB) have been developed for testing the strength of different materials. The modified SHPB apparatus for dynamic bending used in this study has been proposed by [Yokoyama & Kishida (1989)]. The aim of this study was to make a critical review and a comparative study of analytical and numerical methods for processing three-point SHPB bend test with a particular focus on wave shifting. An illustration and application of the method to micro-concrete is given.

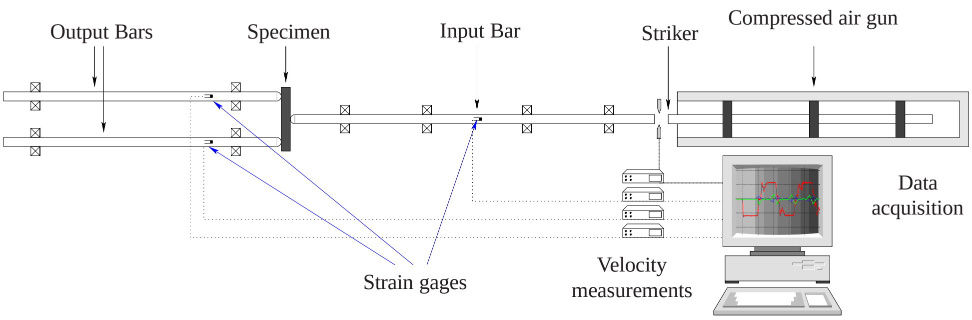

Figure 1: Schematic of bending test set-up and strain gages location

The input velocity V_i and the input force F_i at the contact point between the incident bar and the test specimen boundary were determined using the following classical 1D theory formulae:

$$V_i(t) = -C_B\,(\varepsilon_i(t) - \varepsilon_r(t)) \tag{1}$$

$$F_i(t) = -C_B Z_B\,(\varepsilon_i(t) + \varepsilon_r(t)) \tag{2}$$

where $C_B = \sqrt{E_B/\rho_B}$ is the wave speed and $Z_B = E_B A_B / C_B$ the characteristic impedance. The ε_i and ε_r are the incident and the reflected waves at the input bar/specimen interface. For practical reasons and to allow an easy separation of the waves in the input bar, the strain gages are glued in the middle of the incident bar (fig. 1). The first step of analysis is to shift the incident and reflected waves towards the specimen/bar interfaces. In a dynamic bending test, the mechanical transient response of the specimen imposes a coupling relationship between V_i and F_i :

$$\mathcal{G}_{\tau\in[0,t]}\,(F_i(\tau), V_i(\tau)) = 0 \tag{3}$$

With the use of the equalities (1) to (3), one derives an implicit relation between the incident and reflected waves. During the first instant, the specimen behavior is supposed to remain elastic. Several methods can be used to characterize the elastic coupling relationship (3) :

- simply supported beam in a quasi-static state [Ruiz & Mines (1985)], [Bacon & al. (1994)];
- beam approximated by a single degree of freedom (SDOF) system (Rayleigh's method) [Dutton & Mines (1991)], [Jiang & al. (2004)];
- modal superposition [Sahraoui & Lataillade (1998)], [Rokach (1998a)];
- long beam model (derived from results established by [Ditkine & Proudnikov(1979)]).

The responses of the various models to analytically given loads are compared. For an imposed force ramp, the results are compared to reference solutions obtained using the finite-element method (fig. 2).

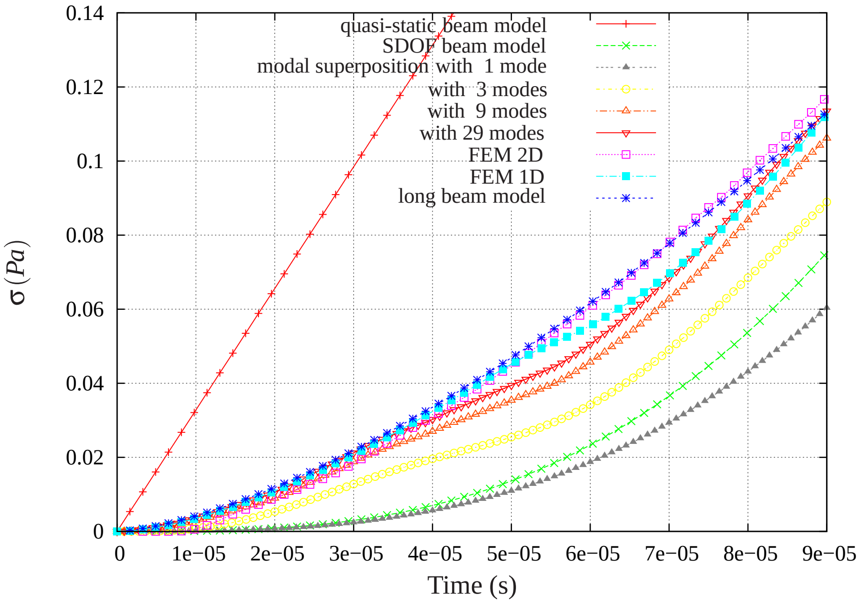

Figure 2: Maximum stress predicted by various models and FEM simulations

The different techniques of wave time shifting are applied to process the experimental recorded data obtained with a micro-concrete specimen. It is found that, in this case, the failure occurs during the first few instants, when bending waves have not yet reached the supports (the mechanical state is identical to that resulting from a one point bending load). As a consequence, only the long beam model and the modal analysis with a relatively large number of modes, can be used to accurately time shifting the waves.

Identifying the best model is an important issue because a small time shifting error involves a large error in the estimation of the input force and in the mechanical strength.

Acknowledgments

The authors would like to thank the French National Research Agency (ANR) for supporting this research (in the framework of the VULCAIN ANR-07-PGCU project)

References

[Yokoyama & Kishida (1989)] Yokoyama T, Kishida K., A novel impact three-point bend test method for determining dynamic fracture-initiation toughness. *Experimental Mechanics* 1989; **29**,(2),188–194.

[Ruiz & Mines (1985)] Ruiz C, Mines R A W. The Hopkinson pressure bar : an alternative to the instrumented pendulum for Charpy tests. *International Journal of Fracture* 1985; **29**,(2),101–109.

[Bacon & al. (1994)] Bacon C, Farm J, Lataillade JL. Dynamic fracture-toughness determined from load-point displacement. *Experimental Mechanics* 1994; **34**,(3),217–223.

[Dutton & Mines (1991)] Dutton A G, Mines R A W. Analysis of the Hopkinson pressure bar loaded instrumented Charpy test using an inertial modelling technique. *International Journal of Fracture* 1991; **51**,(2),187–206.

[Jiang & al. (2004)] Jiang F, Vecchio KS, Rohatgi A. Analysis of modified split Hopkinson pressure bar dynamic fracture test using an inertia model. *International Journal of Fracture* 2004; **126**,(2),143–164.

[Sahraoui & Lataillade (1998)] Sahraoui S, Lataillade J L. Analysis of load oscillations in instrumented impact testing. *Engineering Fracture Mechanics* 1998; **60**,(4),437–446.

[Rokach (1998a)] Rokach I V Modal approach for processing one- and three-point bend test data for DSIF-time diagram determination. Part I-Theory. *Fatigue Fracture Engng Mater Struct* 1998; **21**,(8),1007–1014.

[Ditkine & Proudnikov(1979)] Ditkine V, Proudnikov A. *Calcul opérationnel* Editions MIR: Moscou, 1979.